

Biomass gasifier projects for decentralized power supply in India: A financial evaluation

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Abstract

Results of a techno-economic evaluation of biomass gasifier based projects for decentralized power supply for remote locations in India are presented. Contributions of different components of diesel engine generator (DG) sets, dual fuel (DF) engine generator sets and 100% producer gas (HPG) engine generator sets to their capital costs as well as to the levelized unit cost of electricity (LUCE) delivered by the same have been analyzed. LUCE delivered to the consumers has been estimated to be varying in the range of Rs. 13.14–24.49/kWh (US\$¹ 0.30–0.55/kWh) for DF BGPP. LUCE increases significantly if BGPP is operated at part loads. Presently available 40 kW capacity HPG systems in India are expected to be financially competitive with a DG set of equivalent capacity beyond a break-even diesel price of Rs. 34.70/l. It is expected to be financially more attractive than an equivalent capacity DF BGPP for diesel prices of more than Rs. 44.29/l. In certain specific conditions operating two smaller capacity systems has been found to be attractive as against a single larger capacity system.

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1. Introduction

The all India installed capacity of electric power generating stations under utilities was reported at 123,901 MW as on 31 January 2006 of which contributions of hydro, thermal, nuclear and renewable sectors were 26.0%, 66.4%, 2.7% and 4.9%, respectively (<http://powermin.nic.in>). The shortages in peak electricity demand (10,556 MW) and energy supply (41,630 million kWh) in the country for the period April 2005 to January 2006 were about 11.6% and 8.0% respectively (<http://powermin.nic.in>). Whereas about 20% of 593,732 villages are yet to be electrified, only about 44.0%² of rural households have access to grid supplied electricity (<http://powermin.nic.in>). Government of India has envisaged to electrify remaining villages by 2007 and all households by 2012 (MNES, 2004).

In India, nearly 24,500 villages are classified in the category of ‘remote villages’ where extension of the conventional electricity grid may not be possible in the near future (MNES, 2004). All these remote villages are proposed to be provided with electricity supply from renewable energy based decentralized electricity generating options such as PV, small hydro, biomass gasifiers and wind energy conversion systems under a remote village electrification programme started by the Ministry of Non-Conventional Energy Sources (MNES) of Government of India in 2001–2002. The MNES provides financial assistance up to 90% of the cost of the projects as grant for electrification of remote villages with specific benchmarks (e.g. up to Rs. 1.50 million for a 50 kW biomass gasifier power project) as applicable in respect of technologies adopted for electrification. 1744 remote villages and 572 remote hamlets have been electrified and projects for electrification of 1349 remote villages and 724 hamlets were in progress as on 30 November 2004 under the remote village electrification programme of the Ministry of Non-Conventional Energy Sources (MNES, 2005a). The focus of this programme is mainly on deployment of biomass gasifier power project

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¹1US\$ = Indian Rupees (Rs.) 44.14 on 30 January 2006.

²Whereas 80.0% of villages have access to grid supplied electricity, only 43.5% households have electricity connections.

(BGPP) and micro hydro power projects (MNES, 2005a). In view of the fact the biomass resources (for power generation) are distributed throughout the country as compared to the availability of suitable micro hydro sites, the study focuses on the BGPP for decentralized power supply in India.

The financial viability of power generating projects based on BGPP working in dual fuel³ (DF) or on 100% producer gas⁴ (HPG) mode for decentralized power supply in developing countries is yet to be established. For large scale dissemination of BGPP to meet the electricity demand in remote villages, it is necessary that levelized unit cost of electricity (LUCE) delivered by these projects is the lowest among all the options available to the user⁵. The LUCE delivered by BGPP would depend directly upon the annual amount of electricity delivered and total annualized cost of the project. The total annualized cost of the BGPP normally depends upon the capital cost of the project, cost of fuel(s) (biomass and diesel in DF BGPP and biomass alone in case of HPG BGPP), useful life of its different components (gasifier, DF or HPG engine, generator, civil work, etc.), the discount rate and the cost of annual operation, repair and maintenance of the project. This study aims at providing a detailed techno-economic evaluation of BGPP to supply electricity to remote villages in India in decentralized mode.

2. Biomass gasifier based power project

A biomass gasifier based power project consists of biomass preparation unit, biomass gasifier, gas cooling and cleaning system, internal combustion engine suitable for operation either in DF mode with diesel as pilot fuel and producer gas as main fuel or HPG mode, electric generator and electricity distribution system (Fig. 1). Biomass preparation unit is used to cut the collected biomass to proper size for feeding into the biomass gasifier. Once fed into the gasifier biomass undergoes drying, pyrolysis, oxidation and reduction reactions in a limited supply of air to produce a combustible mixture of carbon monoxide, hydrogen and methane; diluents viz. carbon dioxide and nitrogen; and tar and ash (Kohli and Ravi, 2003). Tar and ash are removed in the cooling and cleaning unit of the gasifier system as they affect the operation and performance of engine adversely. In DF mode operation of engine, diesel or bio-diesel can be used as pilot fuel and producer gas is used as the main fuel but in HPG mode of operation an appropriate provision is to be made for

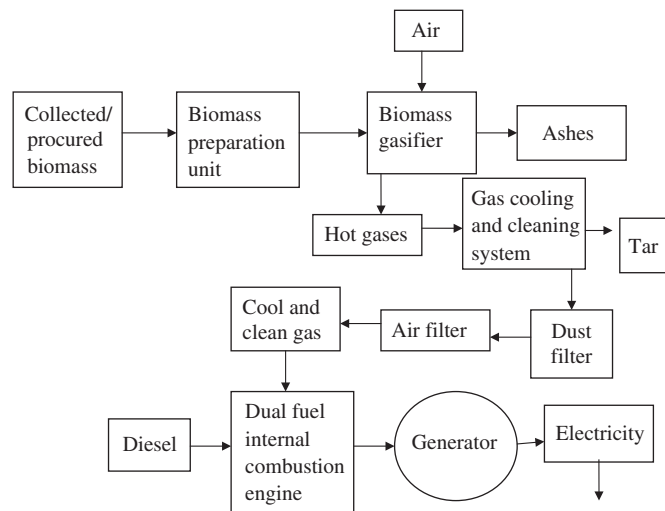


Fig. 1. Schematic of a typical biomass gasifier based power project.

initiating combustion. Use of locally produced bio-diesel as pilot fuel can completely eliminate dependence on diesel especially in remote locations, where transportation of diesel itself may be a difficult task. Electricity generated is distributed to the consumers through a local mini-grid.

The MNES, Government of India has been providing support for promoting development and deployment of biomass resources through combustion, gasification and co-generation technologies for power generation (captive, off-grid and grid connected), and also for thermal applications (MNES, 2005a). For example, the MNES has been supporting development and deployment of biomass gasifiers for almost two decades. As a result, a variety of biomass gasifier based power generation systems of capacities varying in the range of 5–1000 kW_e have been developed indigenously. Most of the biomass gasification systems for electricity generation installed up to 2002–2003 were based on DF engine technology. In recent years installation of BGPP equipped with engines operating on HPG has also been taken up. A total of 1844 biomass gasifier systems (including both DF as well as HPG mode systems) with aggregate capacity of 62 MW_e have been deployed in the country as on 31 December 2004 under the programme implemented by the MNES alone (MNES, 2005a). Under its programme on biomass gasifiers, the MNES is providing capital subsidy to the users for installation of biomass gasifiers. The amount of capital subsidy on pro-rata basis during 2005–2006 is to the extent of 90% of Rs. 1.50 million for a basic package of a 50 kW BGPP project covering housing for system and local electricity distribution network for electricity generation (MNES, 2005b). Engines operating with HPG are also being developed and promoted in India.

Some Indian and international studies on different aspects of financial evaluation and commercialization of biomass gasification technologies are available in literature. Studies have been undertaken for estimation of the LUCE in India for different biomass feed-stocks (Jorapur and

³Diesel is used as a pilot fuel and producer gas is used as the main fuel.

⁴Producer gas typically contains 15–30% CO, 10–20% H₂, 2–4% CH₄, 5–10% CO₂, 6–8% H₂O and remaining N₂ (Kohli and Ravi, 2003).

⁵Though the grid electricity supplied to the domestic and agricultural sectors in India is presently subsidized, the extent of subsidy is being reduced progressively. In this paper, the comparison of the LUCE from BGPP has been made with the estimates of the unsubsidized cost of grid supplied electricity in the remote areas as well as with the cost of electricity provided by diesel based power generating sets.

Rajvanshi, 1993; Kapur et al., 1996; Tripathi et al., 1997; Ghosh et al., 2004; Kishore et al., 2005). Jorapur and Rajvanshi (1993) suggested that capacity utilization factor is a critical factor for making biomass gasifier system financially attractive for electricity generation. Kishore et al. (2005) have also emphasized the view that high LUCE from BGPP in rural areas is due to low capacity utilization factor, which in turn is influenced by purchasing power of the rural people. Kapur et al. (1996) found the unit cost of electricity provided by a DF biomass gasifier using rice husk, as feedstock is financially unattractive compared to grid supplied electricity. However, they concluded that the unit cost of electricity generated compared favorably with diesel-generated electricity for higher capacity systems operating at higher capacity utilization factors. The LUCE from a 500 kW (5×100 kW) DF BGPP installed and commissioned in Gosaba Island of Sundarbans area in the state of West Bengal in India in July, 1997 with capital subsidy from the MNES has been estimated to be financially unviable vis a vis prevailing electricity tariff charged from the consumers during 1999 by the utility (Ghosh et al., 2004). Generation cost of electricity from DF and HPG BGPPs based on levelized cost analysis was found to be about twice that of grid supplied electricity in Indian context (Ghosh et al., 2005). In the context of rural electrification through biomass gasification, Siemons (2001) observed that biomass gasifier systems can be installed and operated in an economically viable manner, even at prevailing cost levels at niche sites. In China, biomass gasification based power generation systems of capacity greater than 200 kW were found to be economically feasible provided the same replace fuel oil and operate for about 5000 h in a year (Leung et al., 2004).

3. Framework for financial analysis

3.1. Electricity delivered by biomass gasifier power project

The annual delivered electricity output (E_o) of a BGPP with rated power output (P) of electricity generator is dependent on its capacity utilization factor (CUF), the fraction of generated power consumed by the auxiliaries of the BGPP (a) and the fraction of electrical losses in the local distribution network (l). It can be estimated using the following expression:

$$E_o = P(8760 * CUF)(1 - a)(1 - l). \quad (1)$$

3.2. Capital cost of biomass gasifier power project

The capital cost of a BGPP (C_{bgpp}) comprises the costs of gasifier (C_g), engine-generator set (C_{eg}), civil works (C_{cw}), and distribution network (C_{dn}).

$$C_{bgpp} = C_g + C_{eg} + C_{cw} + C_{dn}. \quad (2)$$

3.3. Levelized unit cost of electricity

The LUCE is one of the commonly used indicators for financial performance evaluation of renewable energy based decentralized power supply systems such as BGPP (Kandpal and Garg, 2003). The LUCE for a BGPP can be estimated as the ratio of the total annualized cost (AC) of BGPP to the annual electricity delivered by the same, i.e.

$$LUCE = \frac{AC}{E_o}. \quad (3)$$

Total annualized cost can be estimated by taking into consideration the contributions of the capital costs of sub-systems of BGPP through respective capital recovery factors based on their useful lives and discount rate; annual operation and maintenance costs of the different sub-systems of the BGPP and the cost of fuel(s) used. The contributions of capital cost (AC_C), operation and maintenance cost ($AC_{O\&M}$) and cost of fuel (AC_F) to the total annualized cost can be estimated using the expressions as described in Eqs. (4)–(6).

$$AC_C = C_g * R_g + C_{eg} * R_{eg} + C_{cw} * R_{cw} + C_{dn} * R_{dn}, \quad (4)$$

where R_{cw} , R_{dn} , R_{eg} and R_g , respectively, represent the capital recovery factors for civil works, low tension electricity distribution network, engine-generator set and gasifier.

$$AC_{O\&M} = C_g * m_g + C_{eg} * m_{eg} + C_{cw} * m_{cw} + C_{dn} * m_{dn} + 8760 * CUF * m_l * n, \quad (5)$$

where m_{cw} , m_{dn} , m_{eg} , m_g , respectively, represent the operation and maintenance costs of civil works, low tension distribution network, engine-generator set and gasifier as fractions of their respective capital costs. m_l and n , respectively, represent the manpower wage rate and number of manpower required for operation and maintenance of BGPP.

$$AC_F = 8760 * CUF(c_{pf} * s_{spf} * P + c_{bm} * s_{sbmc} * P), \quad (6)$$

where c_{pf} and c_{bm} represent the price of pilot fuel (i.e. diesel or bio-diesel) and biomass respectively. s_{spf} and s_{sbmc} , respectively, represent the specific pilot fuel consumption and specific biomass consumption.

Substituting Eqs. (4)–(6) in Eq. (3) the following expression for the LUCE is obtained:

$$LUCE = \frac{AC_C + AC_{O\&M} + AC_F}{E_o}. \quad (7)$$

In case a fraction x of the capital cost of BGPP is available to user as soft loan at an interest rate d_1 and the remaining $(1-x)$ fraction of the cost is contributed

by the user, the LUCE can be estimated by using the following expression:

$$\text{LUCE} = \frac{AC_g + AC_{eg} + AC_{cw} + AC_{dn} + 8760 * CUF(m_{in} + c_{pf}S_{spfc}P + c_{bm}S_{sbmc}P)}{E_o}, \quad (8)$$

where AC_g , AC_{eg} , AC_{cw} and AC_{dn} , respectively, represent annual costs of gasifier, engine-generator, civil work and distribution network and are estimated using the following expressions:

$$AC_g = xC_g(R_{1g} + m_g) + (1 - x)C_g(R_g + m_g), \quad (9)$$

$$AC_{eg} = xC_{eg}(R_{1eg} + m_{eg}) + (1 - x)C_{eg}(R_{eg} + m_{eg}), \quad (10)$$

$$AC_{cw} = xC_{cw}(R_{1cw} + m_{cw}) + (1 - x)C_{cw}(R_{cw} + m_{cw}), \quad (11)$$

$$AC_{dn} = xC_{dn}(R_{1dn} + m_{dn}) + (1 - x)C_{dn}(R_{dn} + m_{dn}), \quad (12)$$

where R_{1cw} , R_{1dn} , R_{1eg} and R_{1g} , respectively, represent the capital recovery factors for civil works, low tension

electricity distribution network, engine-generator set and gasifier for discount rate d_1 . For a given discount rate (d)

and useful lifetime (T) the capital recovery factor (R) is defined as

$$R = \frac{d(1 + d)^T}{(1 + d)^T - 1}. \quad (13)$$

4. Assumptions and input parameters

The values of all of the input parameters used for estimating the LUCE of BGPP are given in Table 1. The assumptions made in this study in this regard are briefly discussed in this section.

4.1. Capacity utilization factor of BGPP

One of the problems associated with decentralized power projects in remote villages is their low capacity utilization

Table 1
Base values of input parameters used for techno-economic evaluation of biomass gasifier projects for decentralized power supply in India

Input parameter	Unit	Base value
Annual maintenance cost of gasifier as a fraction of its capital cost	Fraction	0.05
Annual maintenance cost of engine-generator as a fraction of its capital cost	Fraction	0.10
Annual maintenance cost of LT electricity distribution network as a fraction of its capital cost	Fraction	0.03
Annual maintenance cost of civil work as a fraction of its capital cost	Fraction	0.02
Auxiliary power consumption by BGPP	Fraction	0.10
Capacity utilization factor	Fraction	0.25
Discount rate	Fraction	0.10
Excise duty	Fraction	0.16
Manpower cost	Rs./man-h	15.00
Manpower requirement for BGPP Of capacity up to 20 kW	Numbers	1
Manpower requirement for BGPP of capacity > 20 kW	Numbers	2
Price of biomass	Rs./kg	1.50
Price of diesel	Rs./l	30.45
Sales tax	Fraction	0.04
Specific biomass consumption in a typical DF engine BGPP at rated capacity	kg/kWh	1.10
Specific biomass consumption in a typical DF engine BGPP at 75% of rated capacity	kg/kW h	1.21
Specific biomass consumption in a typical DF engine BGPP at 50% of rated capacity	kg/kWh	1.32
Specific biomass consumption in a typical HPG engine BGPP at rated capacity	kg/kWh	1.40
Specific biomass consumption in a typical HPG engine BGPP at 75% of rated capacity	kg/kWh	1.54
Specific biomass consumption in a typical HPG engine BGPP at 50% of rated capacity	kg/kWh	1.68
Specific diesel consumption in a typical DF engine BGPP at rated capacity	l/kWh	0.11
Specific diesel consumption in a typical DF engine BGPP at 75% of rated capacity	l/kWh	0.10
Specific diesel consumption in a typical DF engine BGPP at 50% of rated capacity	l/kWh	0.11
Specific diesel consumption in a typical diesel engine at rated capacity	l/kWh	0.30
Specific diesel consumption in a typical diesel engine at 75% of rated capacity	l/kWh	0.28
Specific diesel consumption in a typical diesel engine at 50% of rated capacity	l/kWh	0.30
Transport and transit insurance charges as a fraction of total price	Fraction	0.07
Unit cost of LT electricity distribution network	Rs./km	125,000
Useful life of civil work	Years	20
Useful life of engine-generator set with diesel as pilot or main fuel	h	20,000
Useful life of engine-generator set with bio-diesel as pilot fuel	h	15,000
Useful life of biomass gasifier	h	10,000
Useful life of LT electricity distribution network	Years	20

due to absence of energy consuming productive activities (Ghosh et al., 2005). BGPP for decentralized operation are usually operated for about six hours in the evening for meeting mainly lighting loads (Ghosh et al., 2004). In certain cases BGPP may also be operated during day time for meeting requirement of electricity for operating pumping systems for supplying community drinking water and irrigation and for industrial/commercial loads (such as flour mill), if any. Considering these aspects, a capacity utilization factor of 25% (i.e. CUF = 0.25) has been considered in this study.

4.2. Specific fuel consumption at full loads

Specific biomass (wood) consumption in DF mode of operation of BGPP depends on a number of factors such as type of biomass, its moisture content and calorific value, operating load on BGPP, diesel replacement factor, etc. and is estimated to be in the range of 1.0–1.4 kg/kWh for operation at the rated capacity of BGPP (Gupta, 1993; Tripathi et al., 1997; Anonymous, 2004; Mukhopadhyay, 2004). Specific diesel consumption in dual fuel mode is estimated to be about 0.1–0.111/kWh for operation at rated capacity (Tripathi et al., 1997; Anonymous, 2004). Specific total energy consumption in dual fuel mode of operation of BGPP is higher as compared to specific energy consumption of diesel engine in DG set. It has been reported that specific energy consumption initially decreases with increasing load on DF BGPP and after a particular load it increases and diesel replacements up to 85% have been reported in DF mode of operation of the diesel engine (Uma et al., 2004; Anonymous, 2003a). The specific biomass and diesel consumption in DF mode of operation depend on diesel replacement achieved and at higher diesel replacement rates specific biomass consumption is higher (Anonymous, 2003b). Average fuel wood and diesel consumption per kWh of electricity generated have been reported as 0.822 kg and 0.1351, respectively, for the 5×100 kW BGPP installed in Gosaba Island of Sundarbans, West Bengal (Ghosh et al., 2004). Considering wide variations in reported values of specific biomass consumption (0.822–1.4 kg/kWh) and specific diesel consumption (0.1–0.1351/kWh), in the present study specific biomass and diesel consumptions at rated capacity of BGPP have been considered as 1.1 kg/kWh and 0.111/kWh, respectively.

4.3. Specific fuel consumption at part loads

At part load operation of BGPP, specific biomass and diesel consumption values would however be different. Some studies have been undertaken and have been reported in the literature (Ramachandra, 1993; Uma et al., 2004). These studies clearly indicate that specific biomass consumption increases substantially for a BGPP working in DF mode operating at part loads and specific biomass consumption is the minimum at rated capacity of

BGPP (Ramachandra, 1993). Specific diesel consumption of a diesel engine working in diesel alone mode is minimum in the range 75–85% of the full rated capacity and increases at lower and higher loads (Ballaney, 1980). In DF mode of operation, similar behavior is observed in specific diesel consumption at different loads and specific biomass consumption decreases with increase in load on BGPP (Ramachandra, 1993). In the present study, minimum specific diesel consumption has been considered as 0.11/kWh when BGPP operates at 75% of rated capacity and the same is assumed to increase by 10% when the BGPP operates either at 50% or at its rated capacity. In view of the higher specific biomass consumption at part load operation of DF BGPP, the same have been assumed to be 10% higher than its value at rated load at 75% load and 20% higher at 50% load. In case of bio-diesel as a pilot fuel, in the absence of any published information in this regard, it is assumed that the specific bio-diesel consumption would be higher by a factor determined by the ratio of calorific value of diesel and bio-diesel. Auxiliary power consumption of the BGPP has been reported as 10% of its rated capacity (Gupta, 1993; Anonymous, 2004) and the same has also been used in this study.

4.4. Useful life of gasifier

Very little information has been reported in the literature on operating experiences of BGPP and consequently on the values of parameters such as useful life of gasifier, life of DF engine, maintenance costs, losses in distribution of electricity, etc. of BGPP for decentralized power supply. Although pilot scale gasifiers have been developed and deployed in the field that use advanced materials such as stainless steel and ceramics and reported to offer better performance and longer life (Anonymous, 2003a), the biomass gasifiers in India are generally made of mild steel (Tripathi et al., 1997) primarily due to low cost of mild steel and ease of fabrication with it. Use of mild steel has led to poor performance reliability and low useful life of gasifiers (Ghosh et al., 2005). No authentic data is available for the useful life of biomass gasifiers under Indian operating conditions and the reported operating life of a biomass gasifier is in the range of 2000–15,000 h (Gupta, 1993; Tripathi et al., 1997; Anonymous, 2003b). Useful lives of gasifiers reported in the literature are based on different designs using different materials for fabrication of gasifiers. In the present study, operating life cycle of gasifiers has been assumed to be 10,000 h.

4.5. Useful life of diesel engine operating in DF mode

In-spite of the prevailing practice of using an appropriate gas cooling and cleaning system with the biomass gasifiers, presence of some tars and particulates reportedly affect the critical parts of the engine and also contaminate lubricating oil leading to fast wear of engine parts (Kamat et al., 1993). However, authentic information on the reduction in

operating life of DF engine with producer gas as a main fuel is not available in the literature. An operating life of 20,000 h has been assumed for the DF engine-generator set. Use of bio-diesel as pilot fuel has been undertaken on experimental basis for which hardly any operational information is available as yet. The quality of bio-diesel produced locally in remote locations may not be as good as diesel and therefore, it may have adverse impact on the useful life of engine. The operating life of 15,000 h, respectively, has therefore been assumed for DF engine generator set with bio-diesel as the pilot fuel.

4.6. Price of biomass feedstock

Most biomass gasifiers reportedly use wood chips at present, though there are a few commercial manufacturers offering rice husk based gasifiers as well (Kishore et al., 2005). Estimation of the cost of biomass for BGPP in the conditions prevailing in India is somewhat complicated as the final cost of prepared biomass comprises of several components such as the cost of biomass production, its collection, transportation and preparation to required shape and size. In some situations, biomass feed-stocks may be available at a very low price or even free of cost depending on the location and season. The field price of wood chips is found to vary in the range of Rs. 1000–1500/ton (Kishore et al., 2005; Anonymous, 2004). In the present study the base value for the price of the prepared biomass has been considered as Rs. 1.50/kg.

4.7. Price of diesel and bio-diesel

The price of diesel is assumed at Rs. 30.45/l (the same as its administered price on 16 September 2005 in New Delhi). With regard to use of bio-diesel as pilot fuel for BGPP in DF mode, no authentic price data is available. Moreover, estimates of its price in Indian conditions vary considerably. One study estimates its cost of production as US \$ 0.73/l i.e. Rs. 33.58/l (Openshaw, 2000). Another study estimates its cost in the range of Rs. 17–19/l (Subramanian et al., 2005). A recent study mentions that the use of bio-diesel is hampered by its ad-hoc production and high cost (that lowers demand) and estimates its delivered price as high as Rs. 40/l (Mehendale and Goswami, 2005). The Ministry of Petroleum and Natural Gas, Government of India has fixed the procurement price of bio-diesel at Rs. 25/l (<http://petroleum.nic.in/Bio-Diesel.pdf>). In view of the wide range of reported bio-diesel prices in India, break-even price of bio-diesel as a pilot fuel for DF engine for making BGPP a competitive option vis a vis DG set based option, has been estimated in this study.

4.8. Miscellaneous input parameters

The costs of BGPP to the user considered in this study are inclusive of taxes and duties. Transport and transit insurance costs have also been considered. Cost of local

electricity distribution network has also been taken into account. While length of the electricity distribution network has been considered as 2 km for BGPP of up to 20 kW capacities, the same has been considered 3 km for 30 kW and higher capacity BGPPs. For the 5×100 kW BGPP at Gosaba Island, transmission and distribution losses has been estimated as 13% (Ghosh et al., 2004). In the present study losses in the local distribution network have been assumed to be 10% of electricity produced by the generator.

5. Results and discussion

5.1. Capital cost

The capital cost of a decentralized BGPP depends on a variety of factors including capacity of the project, dual fuel or HPG mode of operation of the engine, location of BGPP, and its technical specifications, etc. Capital cost details of DF BGPP in the capacity range of 5–40 kW and also HPG BGPP of 9 kW, 10 kW and 40 kW capacities during 2004–2005 available from two manufacturers of BGPP in India have been analyzed (Table 2). On comparing the capital costs of DF and HPG BGPP of 40 kW capacities each, it is noted that the cost of both gasifier as well as engine-generator set put together for HPG option is almost twice that of DF option. As a relatively larger size gasifier would be required with HPG mode of operation (due to higher specific biomass consumption as compared to the DF option), to some extent higher cost of gasifier in case of HPG option is logically tenable, but it does not explain about 72% higher cost of gasifier for HPG BGPP option quoted by one of the manufacturers. Similarly, more than double the cost of engine-generator set (Table 2) for the HPG option is difficult to explain purely on account of the expected de-rating of engine and requirement of additional technical features for converting a diesel engine to work in HPG mode. A maximum de-rating of 16% in power for HPG mode has been reported as compared to normal diesel mode of operation at comparable compression ratios (Sridhar et al., 2001). Some researchers are of the view that engines operating on HPG only are not yet commercially available (Kishore et al., 2005) and several technical barriers, are yet to be solved (Ghosh et al., 2005). Another possible reason for such a wide difference in the prices of engines could be due to a rather limited market penetration of HPG engines in India. Moreover, in the prevailing situation, distortions and adhocism in the pricing of HPG BGPP by the manufacturers cannot be completely ruled out.

From relative cost contributions of different components of DF BGPP in the capacity range of 5–40 kW (Fig. 2), it may be noted that as the capacity of BGPP increases, relative cost contribution of biomass gasifier increases. Such a pattern may be attributed to a decrease in relative

Table 2
Cost details of dual fuel and 100% producer gas biomass gasifier power projects (5–40 kW)

Manufacturer of BGPP	Manufacturer I							Manufacturer II			
Type of engine	Dual fuel engine						100% producer gas engine	Dual fuel engine		100% producer gas engine	
Rated capacity of BGPP (kW)	5	10	20	30	40	9	40	10	40	10	40
Gasifier with accessories	76,000	95,000	145,000	300,000	380,000	145,000	700,000	230,000	510,000	250,000	600,000
Biomass cutter	12,000	12,000	12,000	20,000	20,000	12,000	20,000	7,500	7,500	7,500	7,500
Biomass dryer	9,000	9,000	9,000	40,000	40,000	9,000	50,000	10,000	35,000	10,000	35,000
Moisture meter	3,000	3,000	3,000	3,000	3,000	3,000	3,000	5,000	5,000	5,000	5,000
Chain pulley block	0	0	0	10,000	10,000	0	10,000	3,000	6,500	3,000	6,500
Water cooling system	10,000	10,000	15,000	15,000	15,000	10,000	25,000	0	30,000	0	30,000
Other accessories	0	0	0	0	0	0	0	50,000	90,000	50,000	90,000
Taxes and duties	29,700	34,830	49,680	104,760	126,360	48,330	218,160	82,485	184,680	87,885	208,980
Total cost of biomass gasifier	139,700	163,830	233,680	492,760	594,360	227,330	1,026,160	387,985	868,680	413,385	982,980
Engine-generator set	94,000	140,000	245,000	375,000	405,000	200,000	814,000	60,000	400,000	80,000	725,000
Accessories	0	0	0	0	0	0	100,000	0	0	0	0
Taxes and duties	25,380	37,800	66,150	101,250	109,350	54,000	273,780	16,200	108,000	21,600	195,750
Total cost of engine-generator set	119,380	163,830	311,150	476,250	514,350	254,000	1,287,780	76,200	508,000	101,600	920,750
Earthing materials	10,000	10,000	15,000	20,000	30,000	10,000	30,000	15,000	30,000	15,000	30,000
Civil work	60,000	80,000	100,000	150,000	175,000	80,000	200,000	125,000	400,000	125,000	400,000
Erection, commissioning and training	30,000	30,000	30,000	50,000	50,000	30,000	50,000	80,000	100,000	80,000	100,000
Cost of site related work	100,000	120,000	145,000	220,000	255,000	120,000	280,000	220,000	530,000	220,000	530,000
Total installed cost of BGPP	359,080	461,630	689,830	1,189,010	1,363,710	601,330	2,593,940	684,185	1,906,680	734,985	2,433,730
LT electricity distribution network	250,000	250,000	250,000	375,000	375,000	250,000	375,000	250,000	375,000	250,000	375,000
Total cost including distribution network	609,080	711,630	939,830	1,564,010	1,738,710	851,330	2,968,940	934,185	2,281,680	984,985	2,808,730
Cost of BGPP per kW of rated capacity	121,816	71,163	46,992	52,134	43,468	94,592	74,224	93,419	57,042	98,499	70,218

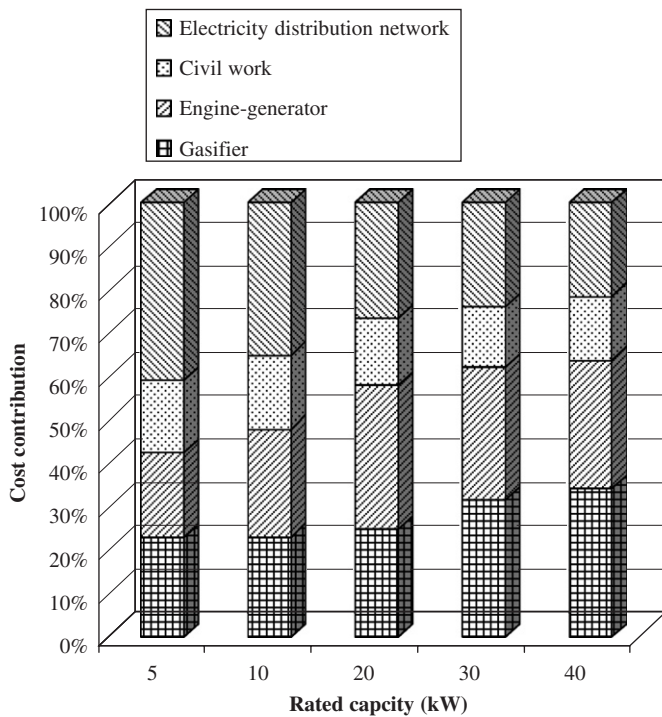


Fig. 2. Relative cost contributions of different components of DF BGPP.

cost of electricity distribution network with an increase in the capacity of BGPP.

5.2. Cost per unit of rated capacity

The cost per unit capacity of DF BGPP, HPG BGPP and DG set based power projects of different capacities

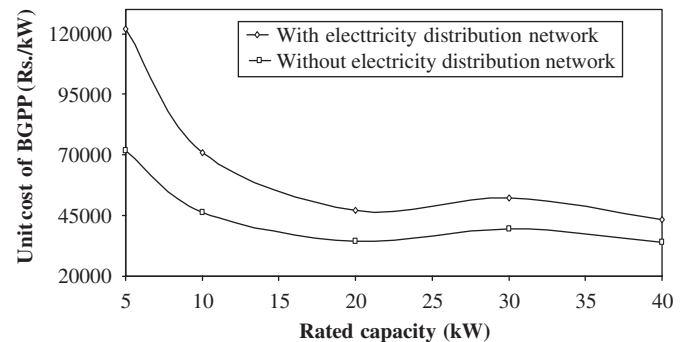


Fig. 3. Cost per unit capacity of DF BGPP.

considered in the present study are presented in Table 2. Economy of scale is observed with increase in the rated capacity of the BGPP. Fig. 3 plotted using data given in Table 2 shows a somewhat abnormal trend for 30 kW DF BGPP. Such a feature may be attributed to the fact that for 30 kW and higher rating BGPPs the cost contribution of accessories such as biomass cutter, dryer and other equipment for measuring moisture, etc increase significantly.

5.3. Unit cost of electricity at full loads

The LUCE estimated based on the base value of input parameters (Table 1) for BGPPs operating in DF and HPG modes and DG set based power projects of the selected capacities are presented in Table 3. It may be observed that DG set based power projects are attractive in terms of the LUCE in comparison to both DF and HPG biomass

Table 3
Levelized unit cost of electricity using different types of power generating systems

Operating load of power generating system as percentage of its rated capacity	LUCE (Rs./kWh)											
	DF BGPP					HPG BGPP		Diesel generating set				
	Rated capacity (kW)					Rated capacity (kW)		Rated capacity (kW)				
	5	10	20	30	40	9	40	5	10	20	30	40
100	24.99	16.84	13.28	14.54	13.14	18.53	15.02	21.38	16.75	14.51	14.26	13.51
75	30.43	20.22	15.48	17.15	15.29	23.26	18.06	23.99	17.82	14.84	14.51	13.50
50	43.23	27.91	20.80	23.21	20.51	33.68	25.92	32.13	22.86	18.39	17.89	16.39

gasifier based power projects for system capacities up to 10 kW. For 20 kW and higher capacity power projects, the LUCE values for DF BGPP option are competitive to the corresponding DG set based options. HPG BGPP does not appear to be financially attractive as compared to DG set based option even for a 40 kW power project. As explained earlier, this is due to the present high cost of HPG based biomass gasifier power projects. With increasing price trend of crude oil in the international market, (it has doubled in less than a year during 2004–2005) and also increasing retail price of diesel in the domestic Indian market in recent times, HPG based BGPP can emerge out as a financially attractive option in near future. The contributions of capital cost, fuel, O&M and electricity distribution to the LUCE for 10, 20 and 40 kW power projects with DF, HPG and DG set based options are presented in Fig. 4. Whereas both the capital and fuel costs have equal role in deciding the LUCE for DF option, capital cost in case of HPG option and fuel cost in case of DG option play dominant roles. With existing local electricity distribution network, the LUCE is estimated to be in the range of Rs. 20.34–12.24/kWh for DF BGPPs in the capacity range of 5–40 kW.

5.4. Unit cost of electricity at part loads

BGPPs installed for decentralized power supply can not always be operating at rated capacity because of the nature of the loads that would be serviced by such projects in remote locations of India. As mentioned in Section 4 and given in Table 1, capacity utilization factor for such projects would be about 25%. It is, therefore, critically important to examine the LUCE of BGPPs at part loads and compare them with DG set based power projects. The LUCE has been estimated for part load operation (75% and 50% of rated capacity) for BGPP operating in DF and HPG modes and also for DG set based power projects in 5–40 kW capacity range and the results obtained are presented in Table 3 and Fig. 5. It is evident from Fig. 5 that at 75% and 50% loads, the LUCE for a DF BGPP in 5–40 kW capacity range is not competitive with an equivalent capacity DG set based power project.

5.5. A single larger capacity system versus two smaller capacity systems

It has been observed that at part loads, the LUCE for a DF BGPP is not competitive vis-à-vis DG set based power projects of equivalent capacity. In most of the remote rural areas industrial loads are almost non-existent and, during the day time, electricity may only be required for operating water pumping systems for community drinking water supply and irrigation and for commercial purposes such as operating flour mill(s). In the absence of industrial and other commercial loads, BGPP would have to be generally operated at part loads. In order to ensure that BGPP is operated near its rated load, the possibility of using two smaller BGPP each with rated capacity of one half the rated capacity of the larger capacity system required to meet the peak load of the remote location/village needs to be examined. A comparison in the capital cost and the LUCE of two smaller systems with a single larger capacity system is presented in Table 4. Whereas operation of only one smaller capacity BGPP could be sufficient to meet daytime load (depending on connected load), both smaller BGPPs would be operated in the evening/night. In the event of having only a single larger capacity system, it would have to be operated at part loads during day time. For the purpose of evaluation, the larger capacity BGPP is assumed to be operating at 50% load during day time. It may be noted from Table 4 that, in spite of a lower unit cost of a single larger capacity BGPP in comparison to two smaller capacity BGPPs, the LUCE for 20 and 40 kW is lower for the combination of two smaller capacity BGPPs.

5.6. Break-even price of diesel

As indicated in Section 5.3, HPG BGPPs can become financially competitive with DF BGPP of equivalent capacities in at least two situations: (i) the capital cost of HPG BGPP reduces considerably from the existing level and/or (ii) the price of diesel used in DF BGPP as a pilot fuel increases. It is therefore, possible to determine the break-even price of diesel for which the LUCE from a DF BGPP is equal to the LUCE from an equivalent capacity

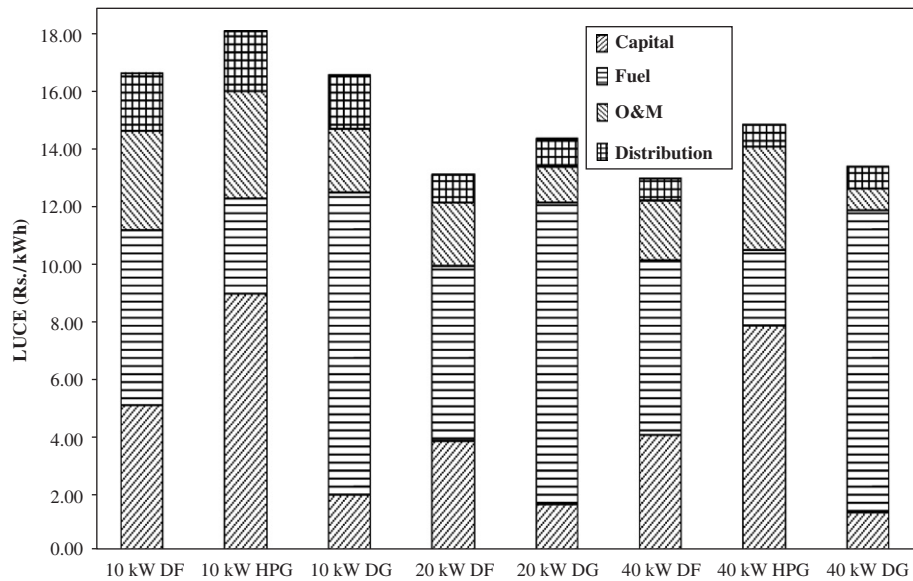


Fig. 4. Comparison of components of LUCE for DF, HPG and DG set based power projects.

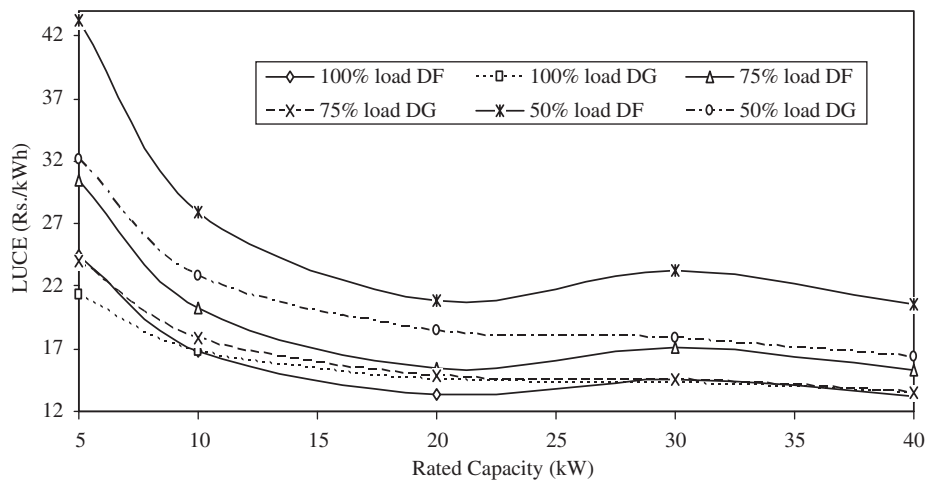


Fig. 5. Comparison of LUCE for DF and DG set based power projects.

Table 4

Comparison of unit capital cost and levelized unit cost of electricity of two smaller capacity BGPP systems with one single equivalent capacity larger system

Attribute of BGPP	Rated capacity of BGPP (kW)					
	10		20		40	
	One 10 kW system	Two 5 kW systems	One 20 kW system	Two 10 kW systems	One 40 kW system	Two 20 kW systems
Unit cost (Rs./kW)	46,163	73,728	34,492	49,973	34,093	36,778
LUCE (Rs./kWh)	18.87	18.90	14.45	13.83	13.66	11.48

HPG BGPP (Appendix A). Based on the cost estimates of a 40 kW HPG BGPP considered in this study (Table 2), the break-even price of diesel is found to be Rs. 34.76 and 44.29/l respectively for making a 40 kW capacity HPG

BGPP option competitive vis a vis DG set and DF BGPP of the equivalent capacities, when operated at rated capacity. At part load operations, break even prices of diesel would further increase.

5.7. Break-even price of bio-diesel

The LUCE for a 40 kW DF BGPP with bio-diesel as a pilot fuel has been estimated for 100%, 75% and 50% of rated loads and the results are presented in Fig. 6. Break-even price of bio-diesel has also been estimated for making it a financially attractive option as a pilot fuel for operation of DF BGPP, as compared to a DG set based power project. Break-even prices of bio-diesel for making DF BGPP of different rated capacities financially attractive to DG set option of the equivalent capacity are presented in Table 5. It may be noted that with the values of input parameters used in the study, the use of bio-diesel as pilot fuel in 5 kW DF BGPP may not be financially attractive as the break-even price of bio-diesel is found to be negative.

5.8. Effect of financial incentive(s) on unit cost of electricity

In remote locations/villages with sufficient biomass availability on year round basis, DF BGPP may be considered as a potential alternative to DG set based power project(s) for electricity supply. As discussed earlier DF BGPP of capacities up to 10 kW are not financially attractive as compared to DG set based power project in terms of the LUCE (Table 3). In order to encourage deployment of BGPP in such remote locations/villages, soft loan to the promoters/owners for deployment of DF BGPP may be considered as one of the potential financial incentives. Considering that 20% of the capital cost of DF BGPP (including cost of local electricity distribution

network) is borne by the user and the remaining 80% of the capital cost is made available to the user as a soft loan at an interest rate of 5%, the LUCE for DF BGPPs of 5–40 kW capacity have been estimated and compared with DG set based power project of the same capacity installed without any financial incentive. The results are presented in Table 6. With the provision of soft loan, the DF BGPP option appears to be a financially better option than a DG set based power project (except for 5 kW capacity system).

The estimated values of the LUCE for a 40 kW DF BGPP for different fractions of capital cost borne by the project owner (an energy supply company or co-operative of energy users) are presented in Table 7. It may be observed that even with 100% capital subsidy the LUCE for a 40 kW DF BGPP is as high as Rs. 7.26/kWh since the contribution of the costs of fuel and operation and maintenance are quite significant. Therefore, the LUCE from a DF BGPP cannot be brought to the level of the average price of electricity (Rs. 1.73/kWh) presently being paid by a user of the domestic sector (Planning Commission, 2003) by providing capital subsidy. The cost of delivering electricity generated by a thermal power station to an un-electrified village located at a distance 5 km from the existing 33 kV electricity distribution network has been estimated as Rs. 9.39/kWh (Chakrabarti and Chakrabarti, 2002).

In cognizance of the fact that there may be considerable uncertainty in the values of the input parameters used in the estimation of the LUCE, the sensitivity of the LUCE for a 20 kW DF BGPP to variations in different parameters

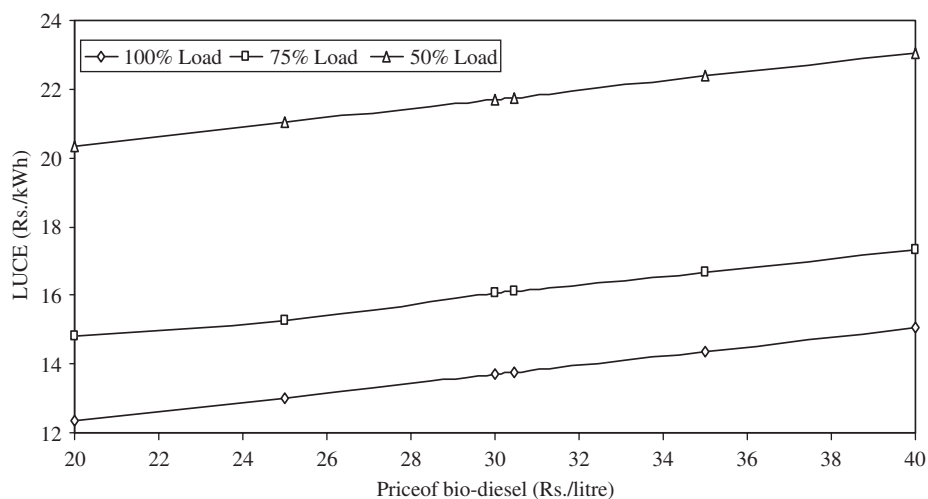


Fig. 6. Effect of price of bio-diesel on levelized unit cost of electricity for a 40 kW DF BGPP.

Table 5

Break-even price of bio-diesel as pilot fuel in DF mode of operation BGPP vis a vis DG set based power project

Rating of power project (kW)	5	10	20	30	40
Break-even price of bio-diesel (Rs./l)	(-)1.01	22.16	32.10	21.50	37.05

such as discount rate, price of biomass, price of diesel, useful life of biomass gasifier and capacity utilization factor has also been studied. The respective base values of these parameters used in the sensitivity analysis are 0.10; Rs. 1.50/kWh; Rs. 30.45/l; 10,000 h and 0.25, respectively. The results are shown in Fig. 7. As expected, the LUCE is sensitive to decrease in CUF and useful life of gasifier and increase in price of diesel and biomass and discount rate.

6. Conclusions

In terms of initial capital cost and unit capital cost, both dual fuel engine based biomass gasifier power projects and 100% producer gas engine based biomass gasifier power projects are costlier to equivalent capacity diesel generator set based power generating options. Capital cost of the HPG BGPP is almost twice that of DF BGPP based on the present prices of these options. The current market prices

of the HPG based engines are high either due to very low demand for such engines and/or due to a pricing strategy of the suppliers of these engines. Among various DF BGPP options up to 40 kW capacity examined in this study, the LUCE for 20 kW configuration is the minimum.

Whereas on the current prices, DF BGPP of capacity greater than 10 kW are competitive in terms of the LUCE with DG based power projects for decentralized power supply, the HPG BGPPs are not yet competitive with either DF BGPP or DG set based power projects. DG set based power projects are found to be financially more attractive as compared to DF BGPP for projects of 5 and 10 kW capacities.

A DF based BGPP needs to be operated at its rated capacity as the LUCE increases significantly if BGPP is operated at part loads (75% or 50% of rated capacity). The results of the study indicate that instead of installing a single large capacity BGPP often operating at part loads for long durations, it may be financially more attractive to install two smaller BGPPs with each having a capacity equal to one half of the larger capacity BGPP. However, such an option usually necessitates higher capital investment.

A 40 kW HPG BGPP can become financially attractive to DG set based power project of equivalent capacity based on the current market prices, at a diesel price of Rs. 34.70/l. Efforts should also be made by the manufacturers to bring down the prices of HPG BGPP and especially the HPG engine. In case bio-diesel is used as pilot fuel in DF engine and it can be established through research and

Table 6

Comparison of LUCE of DF BGPP installed with soft loan (80% of capital cost @ 5%) with an equivalent capacity DG set based power project

Type of power project	LUCE (Rs./kWh)				
	Capacity of power project (kW)				
	5	10	20	30	40
DF BGPP	22.55	15.71	12.54	13.72	12.46
DG set	21.38	16.75	14.51	14.26	13.51

Table 7

Levelized unit cost of electricity of a 40 kW DF BGPP for different fractions of capital cost borne by the owner of the project

Fraction of capital cost borne by the user	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
LUCE (Rs./kWh)	7.26	7.84	8.43	9.02	9.61	10.20	10.78	11.37	11.96	12.55

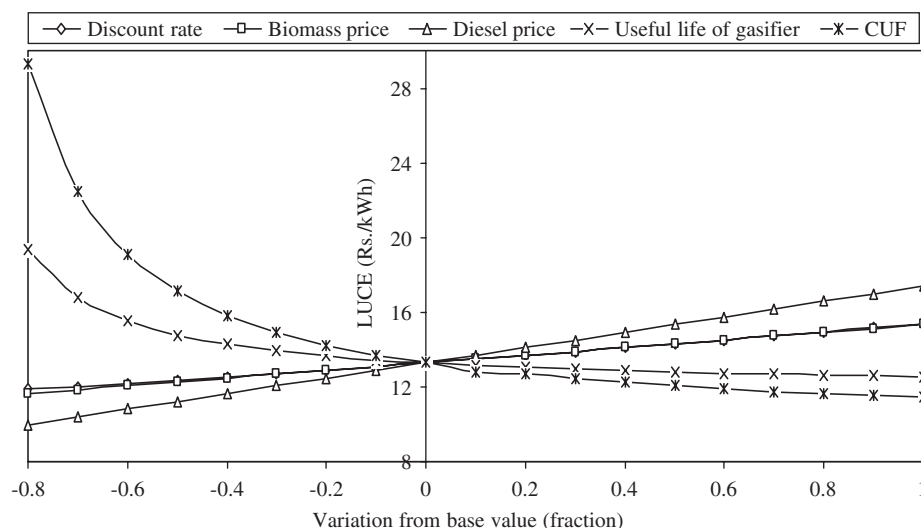


Fig. 7. Effect of variation in the values of different parameters on the levelized unit cost of electricity for a 20 kW DF BGPP.

development efforts that the life and performance of engine are not affected adversely by use of bio-diesel in comparison to diesel as a pilot fuel, switching over to bio-diesel as a pilot fuel would be financially an attractive option if its cost is brought down to about Rs. 22.16/l for a 20 kW BGPP.

Presently capital subsidy is being provided as an incentive for promoting use of DF and HPG BGPPs. Alternatively, to encourage deployment of DF BGPP in place of DG set power projects for decentralized power supply, provision of low interest loan could be considered. A capital subsidy of more than 10% of the total cost of BGPP would make DF BGPP option more attractive than DG set option even for 5 and 10 kW power projects.

With existing local electricity distribution network, the LUCE is estimated to be in the range of Rs. 20.34–11.89/kWh for DF BGPP in the capacity range of 5–40 kW. The feasibility of modifying existing DG set power projects for decentralized power supply to operate in DF mode should also be explored. As expected, the capacity utilization of BGPP and price of diesel have a significant effect on the

AC_{Fhpg} can be estimated using the following expression:

$$AC_{Fhpg} = 8760 * CUF(c_{bm} * s_{sbmc} * P). \quad (A.2)$$

The LUCE for DF BGPP can be estimated using the following expression:

$$LUCE_{DF} = \frac{AC_{CDF} + AC_{O\&MDF} + AC_{FDF}}{E_{ODF}}, \quad (A.3)$$

where AC_{CDF} , $AC_{O\&MDF}$, AC_{FDF} and E_{ODF} , respectively, represent the annualized capital cost, annual cost of operation and maintenance, annual cost of fuel and the annual delivered electricity output of a DF BGPP. AC_{FDF} can be estimated using the following expression:

$$AC_{FDF} = 8760 * CUF(c_{pfDF} * s_{spfDF} * P + c_{bmDF} * s_{sbmcDF} * P). \quad (A.4)$$

At the break-even price of diesel the LUCE from HPG and DF BGPPs should be equal. Using Eqs. (A.1) and (A.4), the break-even price of diesel (C_d) can be estimated using the following expression:

$$C_d = \left\{ \frac{LUCE_{hpg} * E_{ODF} - AC_{CDF} - AC_{O\&MDF}}{8760 * CUF} - c_{bmDF} * s_{sbmcDF} * P_{DF} \right\} / (s_{spfDF} * P_{DF}). \quad (A.5)$$

levelized unit cost of electricity. Therefore, efforts should be made to improve the capacity utilization of BGPP.

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Appendix A

Method used for estimating break-even price of diesel for making HPG BGPP attractive vis-à-vis DF BGPP

By definition, at the break-even price of diesel, the LUCE from a DF BGPP is equal to the LUCE from an equivalent capacity HPG BGPP. Following the approach presented in Section 3.3 of this paper, the LUCE for an HPG BGPP ($LUCE_{hpg}$) can be estimated using the following expression:

$$LUCE_{hpg} = \frac{AC_{Chpg} + AC_{O\&Mhpg} + AC_{Fhpg}}{E_{Ohpg}}, \quad (A.1)$$

where AC_{Chpg} , $AC_{O\&Mhpg}$, AC_{Fhpg} and E_{Ohpg} are, respectively, represent the annualized capital cost, annual operation and maintenance cost, annual cost of fuel and the annual delivered electricity output of a HPG BGPP.

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